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Organization: YAHSGS

Submitted By:

Title:

STTR Phase I: Polar On Line Acquisition Relay and Transmission System (POLARATS)

Project Participants

Senior Personnel

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Worked for more than 160 Hours: Yes

Contribution to Project:

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Worked for more than 160 Hours: No

Contribution to Project:

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Worked for more than 160 Hours: No

Contribution to Project:

Dr. Cooper is a University of Tennessee Professor who served as Consultant to this project. He is an Arctic researcher and advised on Arctic conditions and Arctic deployment issues.

Post-doc

Graduate Student

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Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Oak Ridge National Laboratory

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings:

Training and Development:

Outreach Activities:

Journal Publications

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Categories for which nothing is reported:

Activities and Findings: Any Findings
Activities and Findings: Any Training and Development
Activities and Findings: Any Outreach Activities
Any Journal
Any Book
Any Web/Internet Site
Any Product
Any Contribution

STTR Phase I Final Report

Project Title: Polar On-Line Acquisition Relay And Transmission System (POLARATS)
Number: DMI-0320332

I. Summary

POLARATS (Polar On-Line Acquisition Relay And Transmission System) is being developed by YAHSGS LLC (YAHSGS) and Oak Ridge National Laboratory (ORNL) to provide remote, unattended monitoring of environmental parameters under harsh environmental conditions. In particular, instrumental design and engineering is oriented towards protection of human health in the Arctic, and with the additional goal of advancing Arctic education and research. POLARATS will obtain and transmit environmental data from hardened monitoring devices deployed in locations important to understanding atmospheric and aquatic pollutant migration as it is biomagnified in Arctic food chains. An Internet- and personal computer (PC)-based educational module will provide real time sensor data, on-line educational content, and will be integrated with workbooks and textbooks for use in middle and high school science programs. The educational elements of POLARATS include an Internet-based educational module that will instruct students in the use of the data and how those data fit into changing Arctic environments and food chains. POLARATS will:

- Enable students, members of the community, and scientific researchers to monitor local environmental conditions in real time over the Internet; and
- Provide additional educational benefits through integration with middle- and high-school science curricula. Information will be relayed from POLARATS devices to classrooms and libraries along with custom-designed POLARATS teaching materials that will be integrated into existing curricula to enhance the educational benefits realized from the information obtained.

The Phase I research has fully accomplished the Phase I objectives stated in the Phase I proposal. During Phase I of this STTR project, YAHSGS and ORNL established the feasibility of POLARATS to provide remote monitoring of radioactivity in harsh arctic environments and developed the conceptual design for POLARATS, illustrated in Figure 1.1. Although the Phase I proof of principle tests focused on measurement of radioactivity, POLARATS has been designed to support a variety of sensors as indicated in Figure 1.1. During Phase II a prototype device will be deployed by Tim Buckley, a high school science teacher and Head of the Science Department at Barrow High School in Barrow, Alaska, and Mr. Buckley will use POLARATS within his freshman general science course. In addition, designs for the software system (Figure 2.11) and educational module have also been developed during Phase I.

During Phase I, we:

1. Evaluated POLARATS components and designed a prototype device. We performed a requirements assessment and performance analysis, and completed a conceptual design of POLARATS. Portable detectors, Global Positioning System (GPS) devices, central processing unit (CPU) and translation protocols, and radio transmission devices were evaluated and a prototype was designed for deployment in harsh environments.
2. Tested cold weather performance in an environmental testing chamber and determined the feasibility of accurately and reliably acquiring Arctic field data from remote instruments.

The cold weather performance was tested in the ORNL Environmental Effects Laboratory Testing Chamber down to a temperature of -60 ºC. Two types of radiation detectors were evaluated in Phase I – Geiger-Mueller (GM) and Sodium Iodide (NaI) detectors – and both met accuracy requirements. Responses remained relatively consistent across the entire temperature range for all detectors. Stability proved to be very good for extended exposures in the range of -30 ºC and responses varied by less than 15% at -60 ºC. Although the GM detector showed slightly greater variation at the extreme low end of the temperature range, the accuracy is acceptable for the intended application. GM detectors are both smaller and lower-cost than NaI detectors, and because we place a high premium on size and cost, the GM detector was selected for use in the Phase II device.

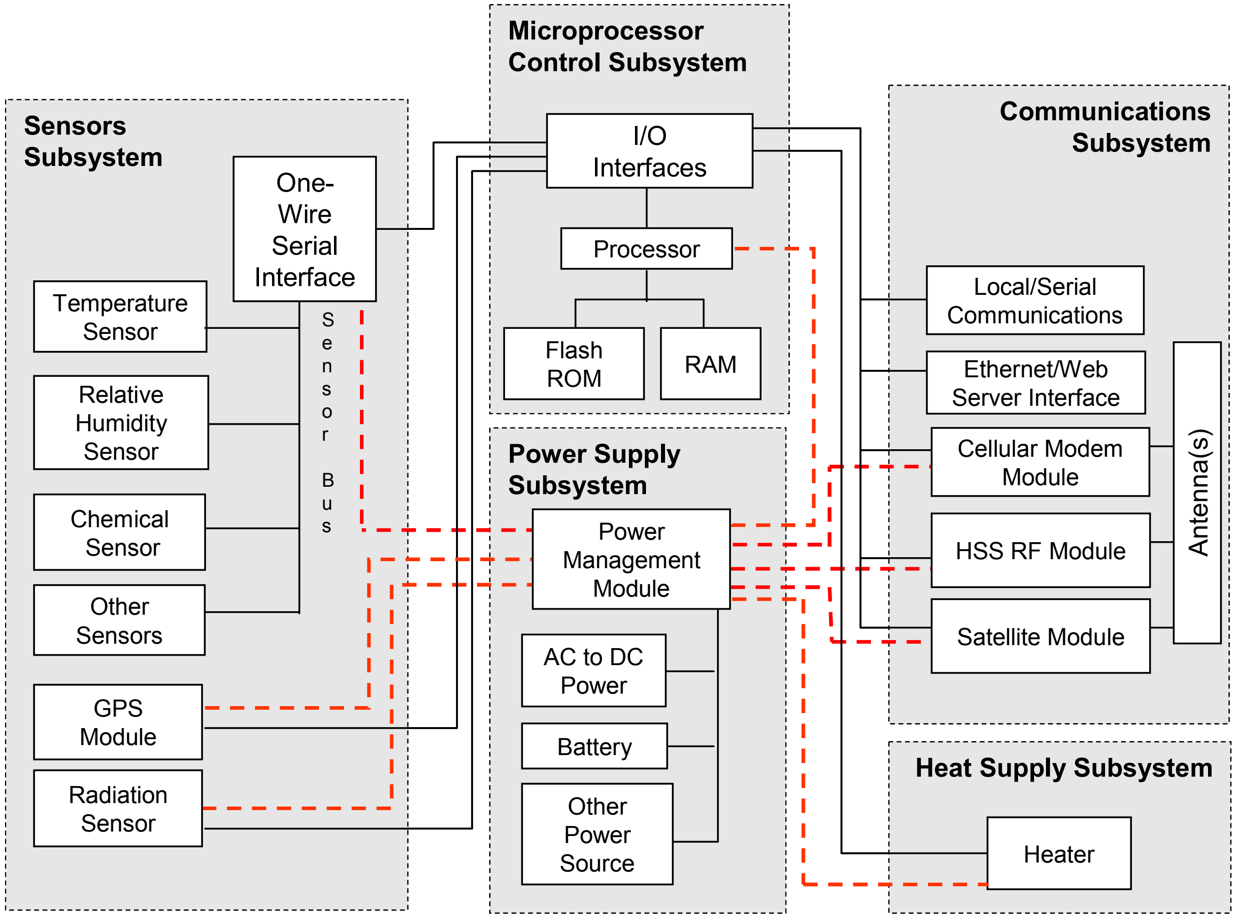


Figure 1.1. POLARATS Conceptual Design: Block diagram of the functional components comprising the POLARATS system.

The POLARATS device consists of climate hardened components that are integrated into a core unit that is capable of accepting radiation, chemical, biological, and other environmental/geophysical monitoring device inputs on a plug and play basis. The device will be the size of a laptop PC and weigh approximately 10 pounds. Each POLARATS system will consist of the following five main functional blocks: (1) a microprocessor control subsystem; (2) a sensor subsystem; (3) a communications subsystem; (4) a power supply subsystem; and (5) a heat supply subsystem.

- The microprocessor control subsystem interfaces with the communications modules, with the sensor modules, and with the power modules using both non-volatile and volatile memory to store the system software, system commands, and sensor data.

- The sensor subsystem utilizes IEEE 1451-compliant protocols for communicating with sensor modules and enables future additions of 1451-compliant sensors. Sensors integral to POLARATS include GPS, temperature, relative humidity, barometric pressure, and radioactivity, while chemical and biological sensors will be add-ons.

- The communications subsystem enables multiple communication links through a serial port or an Ethernet port depending upon the nature of deployment. These include radio frequency (RF); cellular/PCS, such as CDMA or GSM; satellite communications such as a Low-Earth Orbit (LEO) satellite network system (e.g., Iridium); local communications via a serial port used for development, troubleshooting, and/or initial setup (RS232, USB or IrDA); and Ethernet to allow for quick and low cost connection to the Internet for POLARATS systems located at schools, libraries, and other locations with Ethernet connectivity.

- The power supply subsystem provides power to all the other subsystems. The sources of power that may be utilized include battery, AC (line) power, solar cells, wind, and power scavenging devices. The subsystem converts the voltage of the power source to the required voltage for each subsystem. It also performs power management functions to monitor battery condition and power source availability. Climatic hardening will protect against Arctic temperature and humidity ranges as well as physical impact due to dropping and/or bears.

The educational module consists of Internet- and PC-based instructional materials, teach-the-teacher manual and class plans, and an interactive web site where monitoring data are stored, analyzed, and integrated into a variety of trend analyses and display/report output forms suitable for middle/high school student and general community use.

II. Description of Phase I Research and Results

Figure 2.1 below contains a verbatim statement of objectives from the Phase I proposal.

Figure 2.1. Phase I Objectives as Stated in Phase I Proposal

Objective 1 – Select POLARATS Phase I Components and Design a Prototype System.

1-1 What detector(s) provide the required levels of accuracy over varying temperature conditions to the beta and gamma radiation fields of interest?

1-2 Can the electronics of the detectors, GPS, data recorder, CPU, thermometer, and radio transmission device be linked?

1-3 Can all components be hardened for reliable operation in harsh Arctic temperature environments?

1-4 Are key operating components from each device available (e.g., in card or chip form) for assembly into a compact unified hardened operating system suitable for Arctic environments?

1-5 Can an integrated product consisting of detector, GPS, thermometer, CPU, and radio transmission device be designed?

Objective 2 – Demonstrate Accurate and Reliable POLARATS Operation.

2-1 Does the integrated system provide accurate radiation and position information?

2-2 Is Arctic deployment feasible without on-site instrument experts, i.e., can the integrated, hardened system be successfully and routinely deployed by laymen?

The following description of the research performed and research findings is organized according to the Objectives identified in the Phase I proposal (Figure 2.1).

Objective 1. Select POLARATS Phase I Components and Design a Prototype System.

Development of the POLARATS Conceptual Design began with a requirements assessment that included interviews with potential end-users and customers and reviews of experience with other commercial and developmental monitoring devices. As described in Figure 2.2, POLARATS is designed to meet the need for low-cost, reliable, and easily deployed environmental monitoring systems in Arctic regions. It will be integrated into middle school and high school educational curricula and made available on-line to enable local residents to monitor conditions that are critically important to their lifestyles, health, and safety. The POLARATS device resulting from Phase II is designed to have the performance characteristics summarized in Figure 2.3, based upon initial radiation detection deployment using GM detectors.

Figure 2.2. POLARATS Addresses End-User Needs

End-User Need	Weakness of Current Technology	Our Improvement
Information Availability	Arctic environmental monitoring systems are research oriented and do not provide environmental information in a form that is useful to Arctic inhabitants.	POLARATS will empower Arctic inhabitants to understand environmental monitoring information and its relation to their health and safety. Monitoring information is provided in real-time, on-line and in user-friendly formats designed to educate students and be of growing value to Arctic community members concerned about environmental conditions that can affect their health and safety including current conditions and trends.
Information Accuracy and Reliability	Current sensors (e.g., NEWNET 2004) are frequently off-line due to large Arctic climatic changes/component failures.	POLARATS is designed for Arctic temperature, humidity, wind, and precipitation conditions.
Compact and Easily Deployed	Current systems are heavy, bulky, and cannot be easily deployed by non-specialists.	POLARATS will weigh 10 pounds or less and be easily deployed via small boat, snow machine, sled, all terrain vehicle, or backpack.
Ease of Use/Low Maintenance/Plug and Play	Current systems require frequent calibration/maintenance as climatic conditions change, when power outages occur, or when sensors are changed. All require specialized training/knowledge.	POLARATS will be deployable by lay people, will self-calibrate, and will be based on Open GIS Consortium (OGC) standards which will facilitate plug and play capabilities (OGC 2002, 2003).
Low Power Usage	Current systems require frequent battery charging or line power.	POLARATS is based on smart power standards that minimize operating power needs.
Affordability	Available custom systems can cost tens of thousands of dollars.	Basic POLARATS target cost is \$2000 - \$4000 per unit; less as economies of scale are realized.

Figure 2.3. POLARATS Phase II Prototype Performance Specifications

Engineering Specification	Units	Value at End of Phase II
Detection Range	microrem/hour	10 – 100,000
Data At Remote User Workstation	seconds	1 - 2 (continuous connection mode)
Calibration Interval	years	2
Annual Drift	microrem/hour	< 2
Operating Temperature Range	°C	-60 to +60
Operating Humidity Range	% Relative Humidity	10 - 100
Maintenance Interval	years	5 - 10
Size	cm	20 X 20 X 3
Weight	kgs	4
Power Requirements	watts	10
Price	\$/unit	\$2000 - 4000

As part of the requirements assessment, we identified key regulations, standards, and certifications that relate to the design, testing, evaluation, and market acceptance of POLARATS. In addition to state and national educational standards, POLARATS is designed to comply with relevant industrial standards, which include:

- IEEE 1451, Draft Standard for a Smart Transducer Interface for Sensors and Actuators (NIST 2004) is a new family of standards and proposed standards for connecting smart transducers to networks. This emerging standard makes it easier for transducer manufacturers to develop smart devices and to interface them with networks, systems, and instruments by incorporating existing and emerging sensor- and networking technologies. The IEEE 1451 standard was developed to provide common plug-and-play interfaces between smart transducers and sensor control networks. IEEE 1451 implementation enables POLARATS to readily integrate a variety of dissimilar sensors by current and future manufactures.

- Open GIS Consortium (OGC) - OGC is the leading organization for developing open, vendor-independent computing standards for geographic information systems (GIS) and other related technologies. The OGC's core standard is based on the Geography Markup Language (GML), an XML grammar written in XML Schema for encoding geographic information. Although GML provides specifications for describing a variety of geographical information, the fundamental element of GML is a geographic "feature". An OGC-compliant POLARATS will benefit from this "feature" paradigm and will regard almost all of its components as features. These include, but are not limited to, sensors and instruments (in either POLARATS or other OGC-compliant systems), operational data, external databases, etc. A feature can also be an operational (e.g., analysis application, surveillance, decision support, etc.) or an instructional (educational module, simulation application, trend and enumeration package, etc.) component.
- OGC Web Notification Service (WNS) is the first asynchronous messaging service specified by OGC. WNS is a service by which a client may conduct asynchronous message interchanges with one or more other services (OGC 2003).
- OGC Web Feature Service (WFS) describes data manipulation operations on OpenGIS® Simple Features such that servers and clients can "communicate" at the feature level (OGC 2002).
- ANSI N323A, Radiation Protection Instrumentation Test and Calibration of Portable Survey Instruments establishes specific requirements for portable radiation protection instruments used for detection and measurement of levels of ionizing radiation fields or levels of radioactive surface contamination.
- NCRP 57, Instrumentation and Monitoring Methods for Radiation Protection is focused on the calibration of portable instruments used in dose equivalent assessment and the evaluation of surface contamination.
- NCRP 112, Calibration of Survey Instruments Used in Radiation Protection for the Assessment of Ionizing Radiation Fields and Radioactive Surface Contamination addresses the calibration and testing of radiation measurement equipment.
- ANSI N42.17C, Performance Specifications for Health Physics Instrumentation -- Portable Instrumentation for Use in Extreme Environmental Conditions is a performance standard for radiation detectors used under extreme environmental conditions.
- NIST 1297, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results is a national standard that describes methods for estimating and propagating uncertainties in measurement results.
- ICRU 39, Determination of Dose Equivalents Resulting from External Radiation Sources makes it possible to specify, in numerical terms, the degree of irradiation that occurs when individuals are exposed to external sources of ionizing radiation.
- ICRU 33, Radiation Quantities and Units, provides standard radiation quantities and units for data conversion.

Based on the above performance requirements and our performance analysis of key components, YAHSGS developed the POLARATS conceptual design illustrated above in Figure 1.1.

1-1 What detector(s) provide the required levels of accuracy over varying temperature conditions to the beta and gamma radiation fields of interest?

Preliminary Radiation Detector Testing and Evaluation

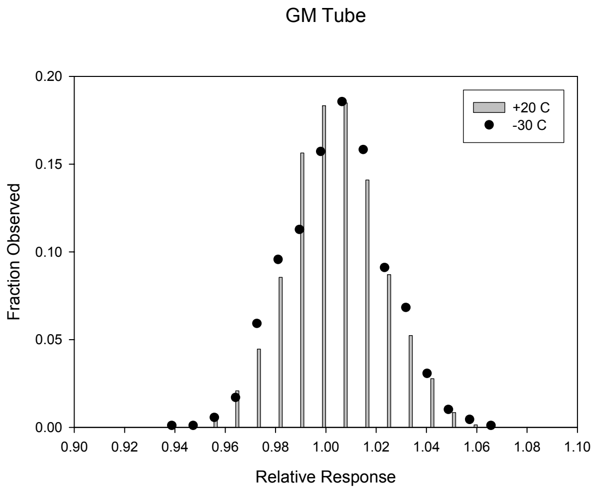
Two different types of detection systems were tested during Phase I. The first was a sealed GM halogen-quenched gas-filled metal tube with dimensions of 1.4 inches (diameter) and 4.5 inches long. The second was a 1.25 inches (diameter) by 1.5 inches long cylindrical NaI(Tl) scintillator coupled to a 1.25 inch photomultiplier tube and dynode voltage divider base (total dimensions of 2 inches by 9 inches long). Figure 2.4 shows both sensor types. The detectors were operated in a gross signal collection mode—i.e., no spectroscopic information was obtained from the scintillation device.

Figure 2.4. The Geiger-Mueller (GM) and Sodium Iodide (NaI) Detectors Tested During Phase I.

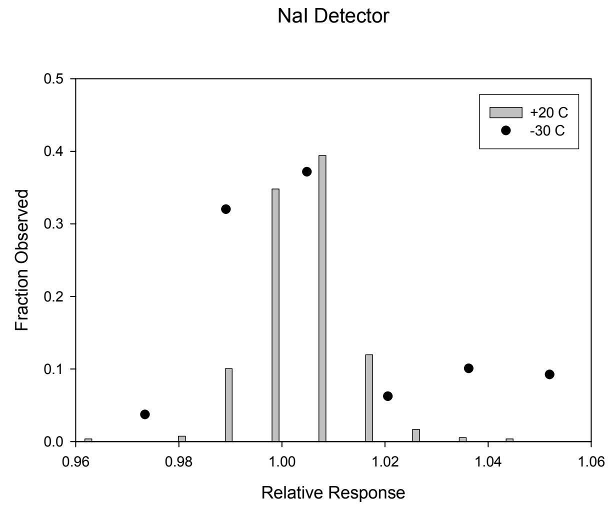
Each system was interconnected to a data collection system to enable automatic collection of measurement readings. This system consisted of a programmable analog/digital data acquisition device interconnected to counting circuitry for each detector. Pulse rates were measured continuously and recorded at five-minute intervals. A Cs-137 source was used to generate steady pulse rates.

Figure 2.5. Experimental Arrangement for Long Term Measurements at -30 ºC.

Both detection systems were operated at room temperature for an extended period to determine their baseline response. The systems were then placed into a laboratory controlled environmental chamber at ORNL (Figure 2.5) and operated for four weeks at temperatures of approximately -20 ºC and -30 ºC to determine long-term operating characteristics at these temperatures. Each detector was operated at each temperature for a minimum of 70 hours. The data were normalized to the median response observed at each temperature and plotted versus observed frequency of occurrence—i.e., a histogram of relative response was generated for each detector at both temperature points. The results are shown in Figure 2.6. The response frequency for the NaI detector system varied in a non-Poisson manner but it was determined that this was not due to temperature variation. Variations in ambient background within the test area—most likely resulting from radon progeny fluctuations—were observed at both temperatures. Since the detectors were being tested at relatively low count rates, the effects of natural background variation were more pronounced for the more sensitive NaI detector.



2.6(a). GM Detector



2.6(b). NaI detector

Figure 2.6. Relative Response Frequency Distribution for the GM Detector (a) and for the NaI Detector (b) Operated at Both 20 ºC and -30 ºC.

In addition, the first GM detector failed abruptly shortly after the initial test series began. Inspection of the failed unit revealed that the problem resided within the sealed detector volume itself and that failure was not associated with the driving electronic circuitry and was not caused by our cold-weather deployment test. An identical unit was selected from the same batch of detectors and the evaluation was restarted. This specific detector survived the entire series and was never replaced.

<u>Testing Across Extended Temperature Range</u>

The systems were next placed into another environmental chamber (Figure 2.7) for testing across a more extended temperature range. Evaluation began at ambient room temperature (20 ºC) and was gradually ramped downward to a minimum value of -60 ºC. The ramp rate was set a 10 ºC/hr with a soak-in of one hour at -60 ºC. A plot of temperature versus exposure time is shown in Figure 2.8. The relative response for each detector is plotted versus ambient temperature in Figure 2.9. The relative response is calculated by dividing the observed response by the original value observed at room temperature.

Figure 2.7. The Environmental Testing Chamber at ORNL's Environmental Effects Laboratory.

Discussion of Results

Responses remained remarkably unchanged across the entire temperature range for both detectors. Stability proved to be very good for extended exposures in the range of -30 ºC and responses varied by less than 15% at -60 ºC. Although the GM detector showed slightly greater variation at the extreme low end of the temperature range, the accuracy is acceptable for the intended application. GM detectors are both smaller and lower-cost than NaI detectors, and because we place a high premium on size and cost, the GM detector was selected for use in the Phase II device.

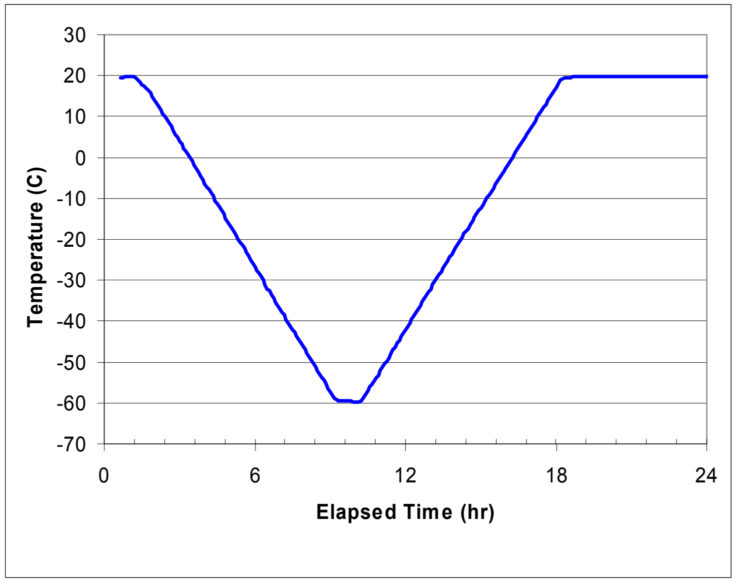


Figure 2.8. Ambient Temperature Profile During Testing at the Environmental Effects Laboratory.

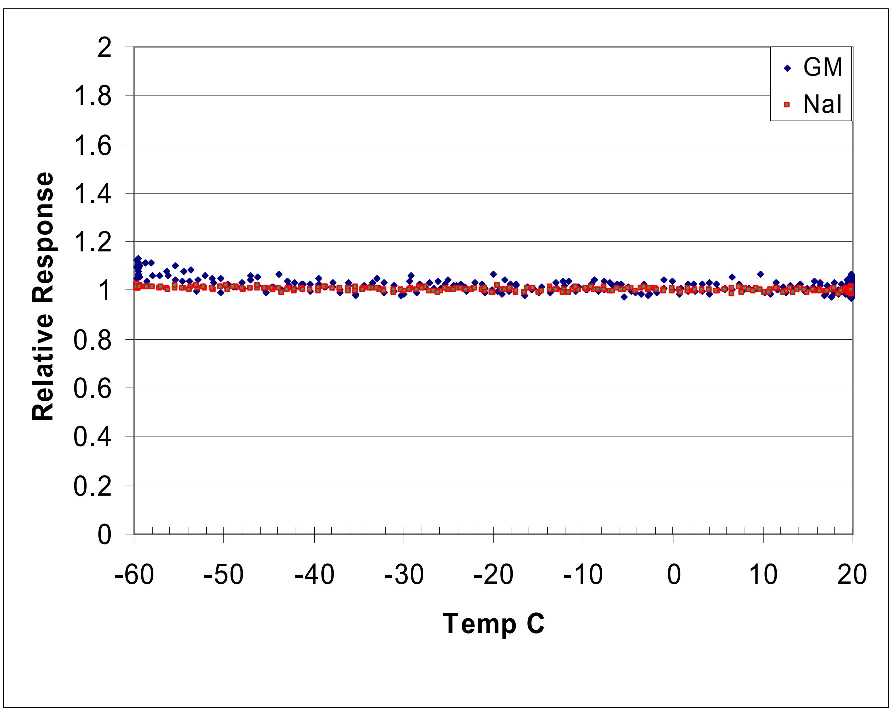


Figure 2.9. Relative Response for the GM and NaI Detectors Versus Ambient Environment Temperature. The relative response is calculated by dividing the observed response by the original value observed at room temperature.

1-2 Can the electronics of the detectors, GPS, data recorder, CPU, thermometer, and radio transmission device be linked?

The electronics required for the POLARATS unit can be linked to meet system requirements. The system will utilize a microprocessor for controlling the various subsystems and reading the various sensors. Each sensor will have its own electronics to operate the sensor as well as to communicate with the microprocessor. In Phase II, communications between the microprocessor and the sensors will utilize serial or USB connections and will utilize an IEEE 1451 Smart Sensor interface for plug and play capability. The microprocessor will communicate over serial, Ethernet, and Satellite systems to the outside world. Communications modules can be added to the system via the serial or Ethernet ports to provide local radio frequency (RF) and cellular based communications. These additional communications methods will be evaluated in Phase II for their potential deployment in a Phase III system.

A key consideration in what sensors and communications devices are to be incorporated into the POLARATS system is the source of power. POLARATS is designed to have sufficiently low power requirements to be met by sources applicable to the application location (battery, AC power, kinetic charging, solar, wind, and fuel cell) lending it well to Arctic applications. POLARATS will include battery operation, however, battery operation will not be able to provide long-term operation, especially with data logging on intervals of seconds (rather than hours or a few times per day). A solar panel to recharge the batteries will provide an effective solution for some months of the year, but not for the entire year. Likewise, for certain applications, wind power will be an appropriate partial source of power. Kinetic charging, fuel cell, and other power sources may also be appropriate for certain applications. The POLARATS system as deployed in Barrow, Alaska in Phase II will operate on an external power source and will also have a battery backup system.

1-3 Can all components be hardened for reliable operation in harsh Arctic temperature environments?

The team also evaluated non-detector components relative to cold temperature and humidity performance. The POLARATS system is intended to operate over a temperature range of +60^{o} C to -60^{o} C. Many industrial electronics components are rated for operation over the range of +80^{o} C to –55^{o} C and routinely operate over such temperature ranges. These electronics components will undergo some performance degradation when operating at extremely low temperatures but will perform adequately for the operating temperature range of the POLARATS system. The electronics components will not experience permanent damage if operated at temperatures below their rated range, so the system can be operated at extremely low temperatures until failure. The system will then recover when temperatures rise again.

It is expected that the integrated system (microprocessor and sensors) will meet performance requirements without any additional hardening; however, batteries, GPS module and commercial wireless communications modules (cellular, Iridium, and local RF) will probably not operate to -60^{o} C. Several expected system components, such as batteries, GPS module, cellular modem and Iridium modem, are rated for a smaller temperature range of +60^{o} C to -40^{o} C at best. Operation at temperature extremes (either high or low) results in reduced performance and sometimes permanent damage or performance degradation. For example, batteries may experience permanent damage if operated below their rated temperature range.

As a result, the design of the POLARATS system incorporates a weather tight enclosure with appropriate connectors to interface power, sensors and communications components. A small heater may be necessary in the enclosure to provide heat when temperatures in the enclosure fall below the rated temperature of any one component, and will be included in the Phase II device to be deployed in Barrow. A temperature sensor will be included in the enclosure, in addition to an external temperature sensor. The microprocessor will be programmed to disable individual components as the temperature within the enclosure falls below (or above) that component’s temperature rating. This is necessary for operating conditions in which external power is not available to power the heater, or if the heater can not maintain a sufficiently high temperature.

A battery power source will be incorporated into the POLARATS system to provide limited data recording capabilities during failure of external power. When external power is not available, the microprocessor will record and store data from the sensors (or possibly only a subset of the sensors). When external power becomes available again, the microprocessor will transmit out this stored data. The best available batteries for low-temperature operation are rated to only -40^{o} C. If external power fails below this temperature or the battery is running out of power, the microprocessor will shutdown the POLARATS system until external power becomes available again.

We believe that the steps outlined above will enable POLARATS to function in the Arctic climate.

1-4 Are key operating components from each device available (e.g., in card or chip form) for assembly into a compact unified hardened operating system suitable for Arctic environments?

Yes – see design and discussion presented in response to question 1-5, below. In particular, the Phase II prototype device is based on available components and is designed to function in the Arctic environment. As discussed above, a weather tight enclosure and heater will be used to provide additional protection. With respect to the full POLARATS conceptual design illustrated in Figure 2.10, a limiting factor may be the availability of chemical sensors capable of operating to -60^{o} C. The Phase I scope of work was limited to testing of radioactivity sensors. Our reviews of operating specifications and interviews with developers of chemical sensors indicate that chemical sensors should also function in POLARATS as designed, however, demonstration of this is left to Phase II of the project.

1-5 Can an integrated product consisting of detector, GPS, thermometer, CPU, and radio transmission device be designed?

System Description

Each POLARATS system will consist of five main functional blocks: (1) a microprocessor control subsystem; (2) a sensor subsystem; (3) a communications subsystem; (4) a power supply subsystem; and (5) a heat supply subsystem. Figure 2.10 shows a block diagram of the POLARATS system.

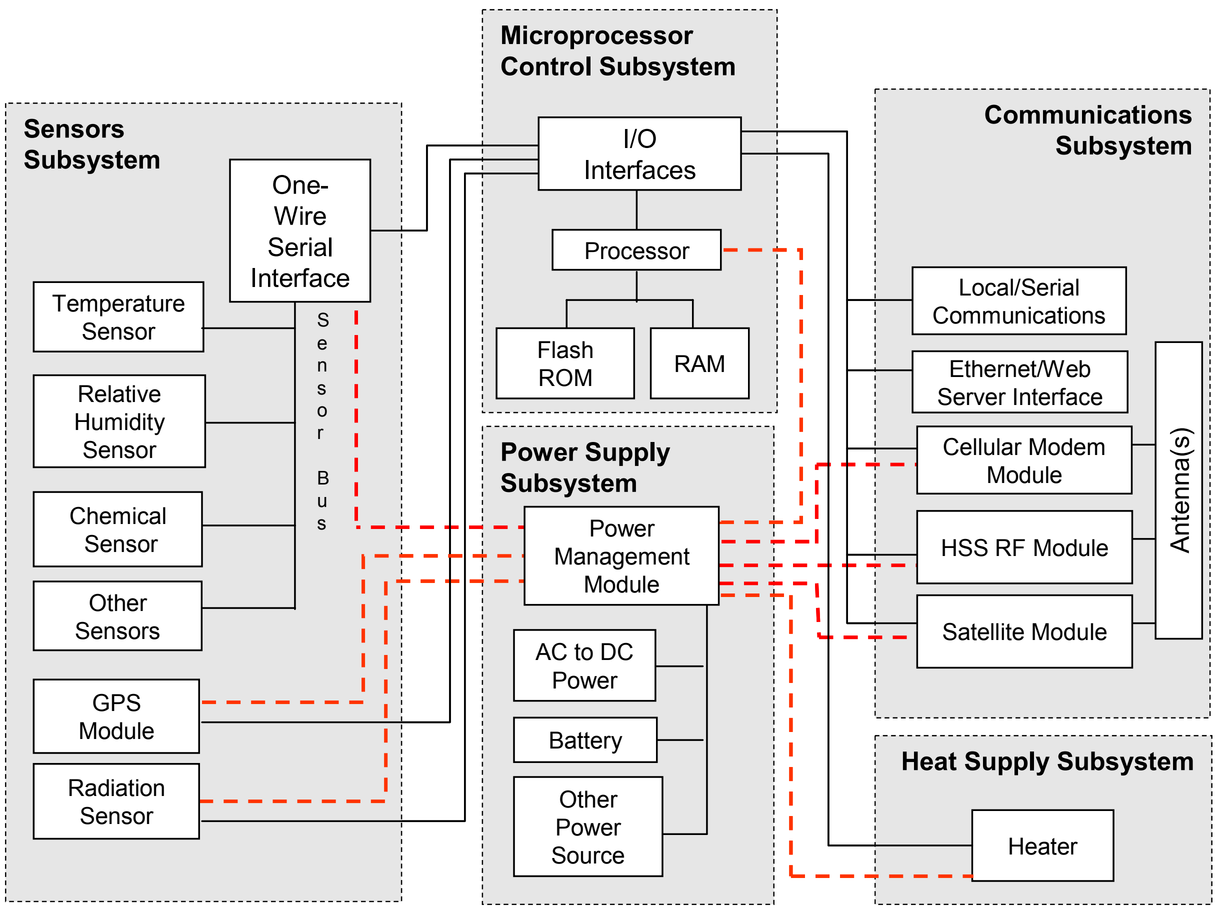


Figure 2.10. Block Diagram of the Functional Components Comprising the POLARATS System.

1. **Microprocessor Control Subsystem**: The microprocessor control subsystem operates as the controller for the POLARATS system. It interfaces with the communications modules, with the sensor modules, and with the power modules. The microprocessor utilizes both non-volatile and volatile memory to store the system software, system commands, and sensor data.

2. **Sensor Subsystem**: The sensor subsystem utilizes IEEE 1451-compliant protocols for communicating with sensor modules. This allows the future addition of any sensor as long as it is compliant with the 1451 protocol. Some of the basic sensors, such as the GPS and the radioactivity sensor, may utilize serial communications ports on the microprocessor. Sensor types that may be part of the POLARATS system can also include temperature, relative humidity, barometric pressure, light, chemical, and others. Additionally, a door switch or other tamper indicating sensor may be included to provide a remote indication of tampering with a POLARATS system.

3. **Communications Subsystem**: The communications subsystem allows multiple different types of communications links to be incorporated into the POLARATS system. They may connect through a serial port or an Ethernet port. The basic communications modes are as follows:

   - RF Communications – the RF communications can take the form of any number of available wireless communications protocols. The RF communications will require a base station to be installed nearby with connection to the Internet.

   - Cellular/PCS Communications – standard commercial cellular analog or digital modems, such as CDMA or GSM, can be utilized by the POLARATS system in some areas of operation. This could eliminate the need to install an RF base station and will be practical in locations such as Barrow where there is cellular phone service.

   - Satellite Communications – a satellite-based communications network can be utilized to provide a remote communications link that can function anywhere in the world. This can provide simpler, more robust, and more secure communications in place of the cellular system. The preferred embodiment would use a Low-Earth Orbit (LEO) satellite network system, such as Iridium.

   - Local Communications – each tag will have a serial port used for development, troubleshooting, and/or initial setup. The serial port may take the form of RS232, USB or IrDA (infrared).

   - Ethernet – the microprocessor subsystem will include a direct Ethernet connection. This will allow for quick and low cost connection to the Internet for POLARATS systems located at a school, library, or other location with Ethernet connectivity.

4. **Power Supply Subsystem**: The power supply subsystem provides power to all the other subsystems. The sources of power that may be utilized include battery, AC (line) power, solar cells, or other power scavenging or generating devices. The subsystem converts the voltage of the power source to the required voltage for each subsystem. It also performs power management functions to monitor battery condition and power source availability. For the Phase II deployment, the POLARATS prototype will use AC and battery power.

Software System Design

In addition to producing the hardware conceptual design above, YAHSGS has also designed the POLARATS software system, illustrated in Figure 2.11 below. Implementation of POLARATS relies on both the electronics discussed above and an application server architecture. This architecture has already been developed by YAHSGS under a separate Phase II STTR grant funded by the U.S. Department of Energy (DOE), currently in progress, for the remote monitoring of decommissioned government facilities. This product is called TOADS for Total On-line Access Data System.

Although TOADS' capabilities are well suited for remote monitoring of decommissioned DOE facilities, its architecture is not fully compliant with the newly emerging open industry standards. Phase I focused on developing the POLARATS software design (illustrated in Figure 2.11) and determining how to adapt the TOADS architecture to POLARATS. For Phase II, we propose to enhance TOADS' architecture and functionality by adopting and implementing two key standards: IEEE 1451 and Open GIS. Figure 2.11 provides the conceptual design of the POLARATS node and its relationship to the enhanced TOADS architecture.

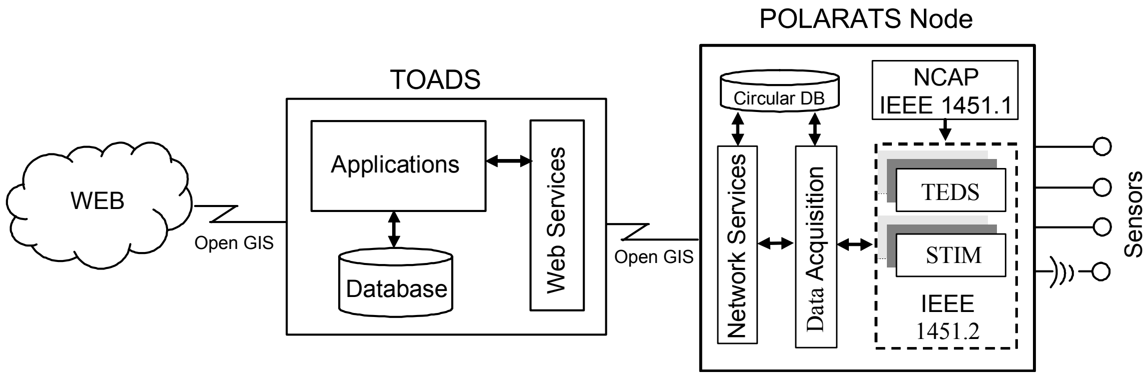


Figure 2.11. POLARATS Software Design.

In Phase II we will complete development of the software system by accomplishing the following:

- **Develop POLARATS NCAP -** Develop NCAP (Network Capable Application Processor) in POLARATS node based on IEEE 1451.1, and in accordance with the existing TOADS architecture. POLARATS NCAP will provide transducer (sensor) application portability, plug-and-play software capability, and network independence.
- **Develop POLARATS TEDS and STIM -** Develop software layers for TEDS (Transducer Electronic Data Sheets) and STIM (Smart Transducer Interface Standard) in POLARATS node based on IEEE 1451.4 (and newly emerging 1451.0) for each sensor/device deployed in POLARATS.
- **Develop POLARATS IEEE 1451/Data Acquisition Interface and Network Interface -** Develop software interface between POLARATS data acquisition process and the above IEEE 1451 implementation layers.
- **Develop POLARATS Open GIS -** Develop POLARATS WNS (Web Notification Service) and WFS (Web Feature Service) software layer. The WNS layer is used to conduct asynchronous dialogues (e.g., alerts, alarms, queries, etc.) between POLARATS and TOADS. The WFS interface layer is used to exchange features (data, application, etc.) between POLARATS and TOADS. TOADS web services will be enhanced by implementing Open GIS WNS and WFS components to enable TOADS to communicate with the POLARATS node.

Educational Module Design

During Phase I we also produced a conceptual design for the educational module based on interviews with middle and high school science and mathematics teachers, publishers of educational materials (Pearson, Addison-Wesley), and instrument resellers who sell to the educational market. The educational module consists of Internet- and PC-based instructional materials written for middle and high school students, teach-the-teacher manuals and class plans, and an interactive web site where monitoring data are presented in real time, stored, analyzed, and integrated into a variety of trend analyses and display/report output forms suitable for middle/high school student and general community use. We also worked with teachers to develop an approach to integrate the educational materials into existing curricula. During Phase II, Tim Buckley, a science teacher at Barrow High School in Barrow, Alaska, will implement this approach within his freshman general science course and provide feedback to further improve the educational materials.

The teachers interviewed stated that a key to successful adoption of the POLARATS product is building successful linkages with existing curricula and state and national education standards. Accordingly, the educational module focuses on providing unique, useful, and interesting information to middle and high school students, initially dealing with Arctic radioactivity, temperature, position, and humidity measurements. The educational module will be carefully integrated into existing middle and high school science and math curricula and be provided locally in the Arctic in relationship with sustaining indigenous cultures in Arctic regions. For example, POLARATS may be used with 6th grade weather curricula, as part of a lesson on weather patterns and the implications of how pollution is distributed by prevailing weather patterns, including Asian dust that is transported across the Pacific and into the Arctic, in some instances resulting in the re-deposition of bomb fallout cesium-137. POLARATS may be used in a 7th grade life sciences class teaching students about how pollution impacts animals and people. In the 8th grade, POLARATS can be used as part of an introduction to radioactivity in the physical sciences curricula. In addition, POLARATS may also be used as part of a middle school mathematics curricula to teach students about graphing and data analysis. POLARATS also has obvious applications to advanced high school physics courses teaching about radiation. In Phase II, POLARATS will be used as part of the Barrow High School freshman general science course which covers ecosystems, human biology, chemistry, and earth science. This course was selected for the demonstration because it will allow us to use POLARATS to aid in teaching a number of different subjects.

POLARATS educational materials will build upon the best of existing educational models and will include the following:

- Teacher training modeled after the training Texas Instruments (TI) provides[1]. TI's educational division offers sensors, laboratory notebooks, teaching materials, and extensive teacher training, and teachers have advised us that the type of hands-on teacher training provided by TI will be absolutely essential for adoption of POLARATS in the educational market. On-line support for teachers will be modeled after the successful JASON Project[2], and in particular, the JASON Academy. The Jason Academy provides an innovative approach to professional development for teachers who want to take content-rich science or mathematics courses anytime, anywhere via the Internet. The JASON Academy enhances teachers' science content background and provides them with the tools to help students learn more effectively. JASON Academy courses have no text materials, but instead use hot-linked references and provide numerous classroom applications with demonstrations and hands-on activities[3].
- Interactive, on-line tutorials for students patterned after the highly successful "The Biology Place" on-line tutorials produced by Pearson[4] (Pearson 2004). For example, Pearson's on-line BioCoach activities allow students to visualize and apply their understanding of biological concepts. During these practice activities, students manipulate graphs, complete biological puzzles, and answer questions. The website is interactive with considerable use of animation to teach students concepts. Each lesson ends with an interactive quiz to aid learning. Pearson's on-line LabBench provides students with pre- and post-lab reviews. Animations and interactive questions connect laboratory procedures to biological principles and the activities include sections on key concepts, experiment design, analysis of results, as well as a lab quiz.
- Workbooks and laboratory manuals modeled after those sold by Vernier[5] for use with their sensors.
- Linkages with existing curricula and state and national education standards modeled after those done by Vernier. Vernier has carefully aligned their workbooks and lesson plans to educational standards for each State, National Education Standards, as well as to the most commonly used textbooks.

Prototype Device Description

Figure 2.10 above illustrates the entire POLARATS concept. The POLARATS prototype device to be deployed in Barrow, Alaska during Phase II will not include all of these functionalities. Specifically, the initial prototype device will not include the "other sensors", "other power source" and cellular and radio frequency modules indicated in Figure 2.10, however, development of solar and wind power sources and the cellular module will continue during Phase II for planned deployment in Phase III.

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[1] Texas Instruments Inc., Educational and Productivity Solutions, http://education.ti.com/educationportal.
[2] The JASON Project, http://www.jasonproject.org/.
[3] JASON Academy, http://www.jasonproject.org/jason_academy/jason_academy.htm.
[4] Pearson Education, Inc. publishing as Pearson Prentice Hall, http://www.phschool.com/statepage/index.cfm.
[5] Vernier Software and Technology, http://www.vernier.com.

Objective 2 – Demonstrate Accurate and Reliable POLARATS Operation.

2-1 Does the integrated system provide accurate radioactivity and position information?

The laboratory testing described above demonstrated the ability of the system to provide accurate radioactivity data. With regard to position information, both Tim Buckley (Barrow High School Science Department Head) and Professor Lee Cooper (Arctic researcher) report no difficulty in use of GPS receivers in Barrow and elsewhere in Alaska. Professor Cooper also reports that onboard the Coast Guard icebreaker that they use for their research expeditions, they have no difficulty establishing location using GPS. He estimates that he currently obtains a position accuracy of better than 50 m using a Garmin GPS.

During Phases I and II, communication is provided via a direct Ethernet connection and satellite phone, although other types of communications links are planned for Phase III, as discussed above. As an additional part of this task, we also investigated data transmission between the sensors and the central data warehouse, including use of XML communication as well as evaluation of raw data transmission. In particular, we investigated options for reducing the "fat" that is introduced by XML encapsulation. Because all XML data are packeted into <start>xxxxx</stop> packets, the additional "capsule" provided by the XML scheme requires additional bandwidth and makes the data packets larger. We investigated use of a structured data stream that does not use data packeting headers/trailers in order to achieve greater transmission efficiency. It was determined that the drawback of this approach is that the format must be hard-coded into both ends of the discussion channel. With XML, only the schema need be understood by both parties. It was decided that for POLARATS' intended primary application, the transmission bandwith required would not be an issue and the benefits of universality provided by XML outweigh any transmission efficiency improvements that could be achieved by using a structured data stream, and so, for Phase II, data transmission will be attained via XML. Although not anticipated at this time, should a need arise to reduce the XML transmission size in the future, we would use small tag names and use a compression technique (such as ZIP) before transmission and then decompress on the other end.

The conclusion that the data transmission bandwith required will not be an issue was based on the POLARATS primary application, which does not include video. If, during subsequent phases of the project, video capability is added to POLARATS, then this must be revisited. If a video capability is added, then compression encoding would be used to reduce transmission bandwidth, for example, using standard "codecs" (e.g., mpeg-1, 2 and 4 etc.) that use variable compression algorithms to reduce the bandwidth as much as possible. This will depend on the specific application requirements, however, because use of mpeg results in reduced image quality; the greater the compression, the poorer the image.

2-2 Is Arctic deployment feasible without on-site instrument experts, i.e., can the integrated, hardened system be successfully and routinely deployed by laypersons?

The Phase II design meets the performance specifications for size, weight, ease of use, low calibration requirements, etc. as listed in Figures 2.2 and 2.3. Based on the design specifications and the successful testing at ORNL's Environmental Effects Laboratory, we have concluded that Arctic deployment is feasible. Tim Buckley, a high school science teacher in Barrow, Alaska, has agreed to deploy the system in Alaska in Phase II – and he also expects deployment to be feasible.

III. Problems Encountered and Methods of Resolution Used

As discussed above, the first GM detector failed abruptly shortly after the initial test series began, but was determined to not be fundamentally related to our cold-weather deployment tests, but rather a manufacturing defect with that specific detector (a second GM detector survived the entire test series and was never replaced). GM detectors are recommended despite this incident because, in general, GM detectors are highly reliable. Halogen-quenched GM detectors are rugged and generally have very long lives. Occasionally, detectors fail due to a physical mishap or fail due to a manufacturing defect, but that is extremely rare. To minimize the possibility of detector failure in POLARATS we will pre-test potential candidate detectors to -60^{o}C prior to deployment. For Phase II, each device will be tested in an environmental test chamber before being deployed in Alaska.

IV. Problems Remaining or Unfilled Research Objectives. None.

V. Conclusions

During Phase I we have accomplished our Phase I objectives and demonstrated the feasibility of providing remote, unattended monitoring of environmental parameters under harsh environmental conditions. We have produced a comprehensive design for POLARATS that provides a strong foundation for the Phase II test deployment. Our interviews with middle school and high school science and mathematics teachers have also demonstrated a desire for this type of real-world teaching aid, provided it can be linked to existing curricula and is intuitive to operate. Involvement of teachers in development of this product from start to finish is considered essential. Mr. Tim Buckley, a high school science teacher in Barrow, Alaska, will deploy the prototype device and use it within his freshman General Science course during Phase II.

POLARATS' key innovations include (a) incorporating the key hardware components into a small climatic and physical shock hardened package that will function in harsh Arctic field applications in order to, (b) integrate real-time environmental monitoring into middle and high school curricula to support standards-based education while also building an awareness of the issues, tools, and information available regarding Arctic environmental conditions and trends, and (c) make the devices highly portable, intuitive to operate, and affordable. These features, not available in any devices/systems today, will facilitate deployment in schools and local communities, as well as by subsistence hunters and fishermen in areas where fish and game are harvested. POLARATS will include "plug and play" capabilities to enable multiple environment-related measurements and changes in deployment with no specialized knowledge required.

POLARATS' primary application is environmental monitoring and education in areas of Arctic Alaska used by people for subsistence food gathering activities who can be adversely affected by global pollutants accumulating in Arctic areas. We will initially focus on inhabitants of Barrow, Alaska, the northernmost community in North America with one of the harshest polar climates. Many Barrow residents rely upon subsistence food sources. POLARATS will enable students and members of the community to view real-time environmental monitoring data online so that they can know, at any given time, the status of their environment and how it potentially affects their traditional lifestyles. One of the benefits of this research is integration of sensor research and development and education. The POLARATS project provides an innovative sensor test bed (the Arctic) with remote access to demonstrate research concepts, educate students, and illustrate future technological directions and is specifically designed to benefit K-12 education as well as to inform local communities. The goal is to attract students to a fruitful interdisciplinary area with clear societal benefits, help build a diverse scientific and engineering workforce, and help realize the potential educational benefits of sensor-enabled science and technology.

Although we are targeting Arctic teachers, students, and members of the public for our initial market entry, end-users may also include researchers, government agencies, and commercial users involved in Arctic research, environmental protection, and resource development. Advantages to end-users include:

- **Lower Purchase Price and Annual Cost** – An off-the-shelf equivalent product does not exist. Potentially applicable systems are custom designed and expensive. POLARATS will be priced for educational markets, will require minimal maintenance, and will have minimal life cycle/operating costs.
- **Less Training/Less Complex With No Specialized Skills Required** – POLARATS is designed to be deployed by a teacher, student, hunter, or fisherman. POLARATS will be compact, light, rugged, and highly user friendly.
- **More Robust (Less Fragile)** – POLARATS will withstand harsh Arctic environmental conditions (-60°C to +60°C; 10% - 100% humidity), be rugged to within trail handling conditions, have sufficiently low power requirements to be met by sources applicable to the application location (battery, kinetic charging, solar, wind, and fuel cell) lending it well to Arctic applications.
- **Works with Existing Curricula/Infrastructure** – POLARATS is designed to be integrated into existing middle and high school curricula.